LOGICAL PROBLEMS OF SYSTEMS ANALYSIS OF ORGANIZATION-AND-ENGINEERING SYSTEMS AND MAIN WAYS TO SOLVE THEM

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UDC 681.51:303.732+519.76

Logical problems of systems analysis of organization-and-engineering systems in the modern industry are discussed. The logical foundations of the systems analysis are analyzed. A methodological function of objective structures in a systems analysis of organization-and-engineering systems is found, and a relationship of these structures as results of analysis and synthesis of objectives is established. The main ways to solve logical problems for systems analysis of organization-and-engineering systems that allow solving logical problems are identified.

Keywords: *production industry, systems analysis, logical problems.*

1. LOGICAL PROBLEMS OF SYSTEMS ANALYSIS IN PRODUCTION INDUSTRY

In the modern production industry, it is possible to separate out the class of organization and engineering systems (OES): research-and-production, industrial engineering, agroindustrial, and fishery. OES include capital-intensive engineering subsystems and are characterized by an especially high uncertainty of situations in these subsystems. In research-and-production systems, the uncertainty is due to scientific and technical progress, in fishery due to fast varying demand on fish products and hardly predictive changes in fishery resources of the World Ocean. Under such conditions, system (logically correct [1]) analysis becomes a necessary component of control processes in the systems, favoring consistent decision making.

However, one often fails to attain a desired consistency of decisions made in OES during systems analysis because the definition of objectives and analysis and synthesis of objectives dominating in it are weakly structured. This leads, on the one hand, to contradictory purposes put forward by subjects of control, and on the other hand, to inconsistency of the purposes and problems (current situations in the systems), to the choice of systems and schemes of meeting the objective that do not ensure reaching the objectives formulated, and finally, to a partial solution of problems.

Since errors in the results of systems analysis are frequently revealed during realization of controls and even after its completion [2, 3], and the cost of their elimination appears too high in OES [2], the practical significance of the solution of logical problems of systems analysis is doubtless. But for a huge number of methods and tools of systems analysis, from PATTERN [4] to Expert Choice [5], Spider [6] and the like, the technologies grounded on them do not ensure the absence of paralogisms and inconsistency in decisions made. The inconsistency of results from systems analysis of OES calls for new approaches and methods of correct definition of objectives and the analysis and synthesis of objectives, which would prevent or timely detect, identify, interpret, and eliminate logical errors.

2. STATE OF THE LOGICAL FUNDAMENTALS OF SYSTEMS ANALYSIS

Initially, the logical fundamentals of systems analysis were developed differently in the USSR and abroad. Since the foreign approach was not oriented toward the use of strict logical models and methods, the informative side of its stages, most important of which is target analysis, did not receive a theoretical substantiation and was expressed in practical

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 1060-0396/06/4203-0426

guidelines generalizing the experience of systems analysis, for example [7, 8], and their treatment was laid to analysts and administrative staff of systems.

From the very beginning, the domestic ways of developing logical fundamentals of systems analysis were theoretical and methodological. Noteworthy are some important results obtained in this area of research: conditions of formulating a strict definition of the concept of a system and its logical nature [9] have been established; stages of development of a system paradigm [10] have been defined; the logical analysis of the systems approach [11] has been performed; hierarchy of system types has been proposed (static $\rightarrow$ dynamic $\rightarrow$ evolving), each preceding being an approximation of the subsequent one; they are associated with logical calculus used to construct logical system theories [9]; information fundamentals of whole–part logic [12] have been developed; law of dependence of system potentials on their structures [13] has been established; decision-making scheme in purposeful systems [14] has been proposed; relations of systems analysis, decision theory, artificial intelligence [15, 16] have been established; logical and methodological analyses of the basis of system theory [17] are carried out; and principles and scheme of organization of system-structural analysis [18] have been worked out.

The methodological aspect of systems analysis is reflected in the definition of this term: "a set of methodological tools used to prepare and substantiate decisions" [19]. This aspect is reflected implicitly [20, 21] in modern interpretation. This makes it possible to conclude that the main methodological problems of systems analysis have been solved, and the unsolved problems are unessential for the quality of its results. However, the inconsistency of the results of systems analysis of the class of objects in question indicate the opposite: the existing methods and tools turn out to be insufficient "to prepare and substantiate decisions" in OES; therefore, logical fundamentals of systems analysis should be developed.

3. WAYS OF SOLVING LOGICAL PROBLEMS OF SYSTEMS ANALYSIS IN OES

To clarify the possible ways to develop logical fundamentals of systems analysis in OES, the general structure of methodological knowledge [22] and the classification scheme of system studies proposed in [23] were analyzed. As a result, the scheme has been updated, which made it possible to position systems analysis of OES in a "space" of theoretical-methodological tools of system studies (Fig. 1).

Erroneous results of systems analysis of OES are in many respects due to the inconsistent structures of the objectives formed during the analysis and synthesis of the objectives of the systems, and systems and plans of attaining an objective are inconsistent with the objective structures due to the similarity of methodological regulatives[1] of systems analysis (along with general system theory [23–25] and systemology [8], the latter is intended for analysis of any objects that admit integrated system consideration. Therefore, the following theoretical and methodological tools of systems analysis of OES should be developed:

— theoretical tools of reasoning about the OES purposes being analyzed[2]; and

— methodological tools of systems analysis of OES, in particular, correction of the logical aspect of the regulative basis: a system paradigm and principles[3].

Let us point out some important points concerning the above means. The analysis and definition of objectives, the choice of systems and schemes to achieve them are grounded on the world-view of subjects of control, their intuition, value system, bioprograms, and natural language. In systems analysis of OES, an organizing role is assigned to tree structures of objectives. Being consistent results of the analysis and definition of objectives, such structures become logical (integrative) foundations of the corresponding systems and schemes of achieving objectives. However, such a methodological position, so important for the control of OES, remains just a declaration because of the insufficient development of models of objectives and reasoning about them. The absence of models for correct reasoning about the objectives analyzed and defined, leads to errors in preliminary decisions in OES, which are assumed to be of system status.

A methodological function of the structures of objectives formed during the analysis and definition of objectives follows implicitly from the metaphor of processes with reciprocal passage of time, used by Academician G. S. Pospelov in

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[1]The regulative technique of applying ideas, concepts, and principles, along with a constitutive one, was introduced by Kant [19, p. 273]. In contrast to constitutive components, regulative ones "appear as ideals and directing forces" of cognitive activity. In system studies, an interpretation (close to Kant's one) of methodology regulatives as a framework of human mental activity [18] is given in [23].

[2]Agrees well with the ideas expressed in [9].

[3]Agrees well with the analysis results presented in [10, 15, 17, 18].

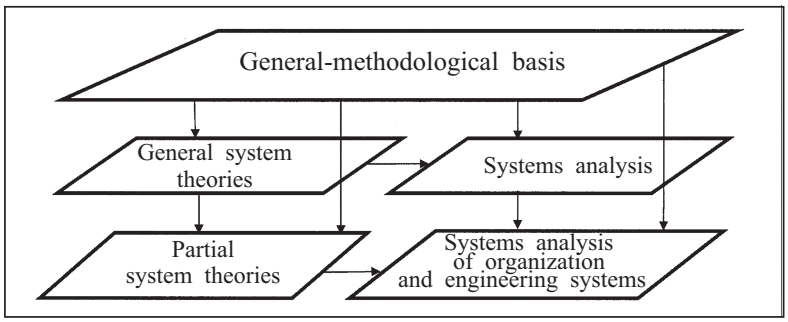

Fig. 1. The place of systems analysis in a classification scheme of methodological and theoretical tools of system study.

[16] for graphs of objectives. Since structures of the objectives play a defining role in the solution of logical problems of systems analysis of OES, we will call the logical fundamentals of this specific domain of systems analysis the structural and objective analysis and synthesis of OES.

4. INCORRECTNESS LEVELS OF THE PROCESSES OF SYSTEMS ANALYSIS OF OES

Separating out possible levels of incorrectness of the processes of systems analysis of OES makes it possible to distinguish types of logic errors in its results and promotes their earliest detection.

Let us associate the level of inconsistency of the processes of systems analysis of OES with intrastage monostructural logic errors. They consist in skipping important links in objective structures (problems, criteria, and functions), the disorder of elements in structures, and the incomparability of directly coupled elements of structures.

Let us associate the level of inconsistency of the processes of systems analysis of OES with interstage polystructural logic errors. They imply the inconsistency of the objectives and problems solved and systems of attaining objectives (their functions and structure), schemes and plans of attaining objectives and objectives structures obtained during the analysis.

5. SOURCES OF LOGIC ERRORS IN THE RESULTS OF SYSTEMS ANALYSIS OF OES

In spite of the fact that system models should coordinate interactions of controlled objects, it is not always possible to implement correctly such a coordination, as it was mentioned in [1]. Let us specify the sources of logic errors in the results of systems analysis of OES, using the methodology of system engineering [7].

One of the principles of this methodology states that “it is more important to select “correct” objectives rather than a “correct” system. To select a wrong objective means to solve a wrong problem; to select a wrong system just means to select a non-optimal system” [7]. Since analysis and definition of objectives produce hierarchical structures of objectives, an incorrect intermediate objective may cause definition of wrong lower-layer objectives and partial attaining of higher-level objectives. The regulative role of objectives necessitates moving subjective processes of their analysis and definition (which cannot be made consistent based on intuitive reasoning) to an objectivistic discursive level.

At the same time, it is impossible to eliminate the subject of control from processes of the analysis and definition of objectives since definition of objectives cannot be represented algorithmically. Along with the variety of types and complexity of the objectives of OES, uncertain formulations and variable verbal descriptions with their semantic equivalence, insufficient study of semantics of objectives, relations between them, and tools of reasoning about them, we assume to describe objectives and discuss them using tools close to natural language. The absence of such tools, on the one hand, and logic errors in the results of analysis of objectives, on the other hand, require to study and develop an appropriate formalized theory of reasoning on the objectives of OES, which would transfer these processes from an informal (subjective and intuitive) to a formalized (subject-objectivistic and discursive) level. This theory, based on the informative aspect of objectives and relations between them, will make it possible to solve the problem of inconsistency of the analysis and definition of objectives and their results.

Another principle of the methodology of system engineering, which states that "objectives provide a logical basis for synthesis of systems" [7], allows us to conclude that logically erratic structures, as the results of the analysis and definition of objectives in systems analysis of OES, do not fulfill their methodological function.

The above reasoning allows us to specify ways of solving logical problems of systems analysis of OES. To this end, we will specify the following integrated stages of systems analysis: (A1) detection of a problem situation and (A2) designing and implementing the process of making coordinated decisions to eliminate the problem situation. We will use the regulative roles of objectives in the creation, operation, and development of OES and the methodological function of objective structures in systems analysis of objects of the given class. To this end, let us specify the phases of systems analysis of OES: the structural-objective analysis (SOA) and structural-objective synthesis (SOS). Moreover, we stratify the stages constituting these phase and define for each of them: (B1) logical stratum and (B2) mathematical stratum. Using tools of reasoning about objects of the analysis and synthesis (purposes, criteria, functions, etc.) and coordination of the results of the indicated processes based on the semantics of data domain, consistent and coordinated with each other data structures of objects are formed on logical strata. A choice from consistent and coordinated objects is performed on mathematical strata using tools treated separately from semantics of the data domain, according to the established criteria and constraints.

6. ANALYSIS AND SYNTHESIS OF OBJECTIVES AND THEIR STRUCTURES

Being purposeful systems, OES in the production industry are formed to achieve the ultimate objectives determined by the needs of the environment and objectives of macrosystems. Since the quality of solution systems produced in a two-phase process depend on the correctness of reasoning about the ultimate objectives of OESs performed at the SOA phase and on the quality of objective structures obtained in this case, let us consider a relation of the results of analysis and synthesis of objectives.

Objective Structure as a Result of Analysis. Analysis and definition of objectives in OES is a multistage process of passage from complex and uncertain ultimate objectives of the systems to less complex and more definite objectives. We will call the hierarchical structure resulting from the indicated process analytic (a) and present it as an m-level graph G^{a}: $G^{\mathrm{a}} = (\mathrm{O}, R)$, where O is the set of objectives of the ith levels ($i = 0(1)(m-1)$); R is the set of arcs of the graph that correspond to the set of subordination between objectives of its upper and lower levels, which express the conditions of attaining objectives being the tools of their attaining [16].

With this graph in view, let us consider a tuple $\mathrm{O} = <\mathrm{o}_{(0)}, \mathrm{o}^{(0)}_{(1i_1)}, \mathrm{o}^{(1i_1)}_{(2i_2)}, \ldots, \mathrm{o}^{(m-2)i_{(m-2)}}_{(m-1)i_{(m-1)}}>$ that consists of the set of objectives of the system, beginning with upper- (zero) level objectives and ending with lower- ($(m-1)$th) level objectives, where $\mathrm{o}_{(0)}$ is the zero-level (ultimate) objective; $\mathrm{O}_{(i)} = \{\mathrm{o}^{(i-1)j_{(i-1)}}_{(i)(j_i)}\}$ is the set of j_ith objectives of the ith level ($i = 1(1)(m-1)$, $j_i = 1(1)n_i$, n_i is the number of objectives) subordinate to $j_{(i-1)}$th objectives of the $(i-1)$th level ($j_{(i-1)} = 1(1)n_{(i-1)}$, $n_{(i-1)}$ is the number of objectives).

Let us write the set of arcs of the graph as follows: $R = \left\{\mathrm{o}^{(i-1)(j_{i-1})}_{(i)(j_i)}, \mathrm{o}^{(i)(j_i)}_{(i+1)(j_i+1)}\right\}$.

Figure 2a shows an example of the analytic structure of objectives. If we generalize the complex process of compiling plans according to [16] and arrange in time the levels of the graph $G^{\mathrm{a}} = (\mathrm{O}, R)$, i.e., assume that decisions concerning objectives are formed as a sequence of events in times t_i $(i = 0, 1, \ldots, m-1)$, then we obtain a graph $G^{\mathrm{a}}_{t_i} = (\mathrm{O}, R, t_i)$ that reflects the process of target scheduling. This process evolves from the node $\mathrm{o}_{(0)}$ of the graph $G^{\mathrm{a}}_{t_i}$ toward its lower-layer objectives $\mathrm{o}^{(m-2)i_{(m-2)}}_{(m-1)i_{(m-1)}}$ (see Fig. 2a, where the process is displayed by the arcs oriented downwards).

During the analysis of objectives and definition of sub-objectives, let us allocate a procedure of forming a "bush" of objective structure. We will specify such a "bush" as a two-level graph $G^{\mathrm{a}}_k = (\mathrm{O}_k, R_k)$, where O_k is the set of objectives, $\mathrm{O}_k = \{\mathrm{o}^{(i-1)(b)}_{(i)(a)}, \mathrm{o}^{(i)(a)}_{(i+1)(c)}, \ldots, \mathrm{o}^{(i)(a)}_{(i+1)(c+l_k)}\}$, including the objective $\mathrm{o}^{(i-1)(b)}_{(i)(a)}$ $(a \in n_i, b \in n_{i-1}, c \in n_{i+1})$ and its sub-objectives $\mathrm{o}^{(i)(a)}_{(i+1)(c)}, \ldots, \mathrm{o}^{(i)(a)}_{(i+1)(c+l_k)}$, l_k is the number of sub-objectives; R is the set of relations of subordination of sub-objectives $\mathrm{o}^{(i)(a)}_{(i+1)(c)}, \ldots, \mathrm{o}^{(i)(a)}_{(i+1)(c+l_k)}$ with the objective $\mathrm{o}^{(i-1)(b)}_{(i)(a)}$.

Let us stratify this procedure: B1) at the logical stratum, we will justify the consistency of the "bush" of objectives;

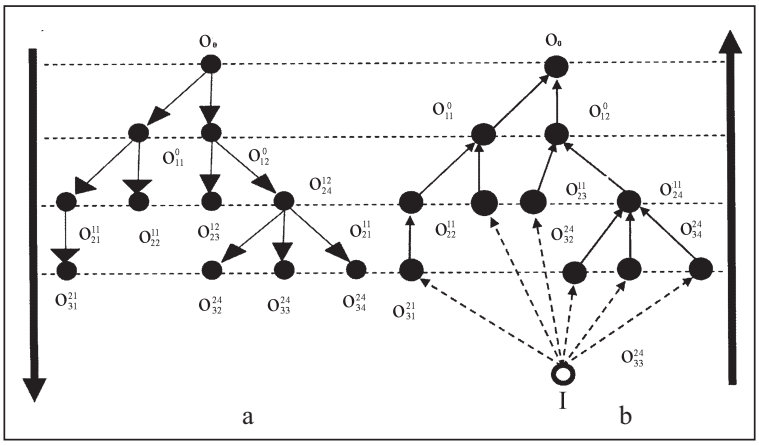

Fig. 2. Relations between the objective structure (a) and scheme of attaining an objective (b) in structural-objective analysis and synthesis of OES

B2) at the mathematical stratum, we will select rational alternatives of strategies of the analysis of objectives and sub-objectives.

Objective Structure as a Result of Synthesis. Synthesis of the objective structure as a scheme of attaining an objective is a multistage mental process of passing from simple purposes to complex ones. This process results in a network structure of objectives. We will call such an objective structure, with an inverse direction of arcs relatively to the corresponding analytic structure, synthetic (s).

In the synthesis of the scheme of attaining an objective, let us separate out the procedure of forming a "bush" of the given network structure of objectives, which implies improvement of the objective using its sub-objectives, and stratify it: B1) at the logical stratum, we will comprehensively justify the correctness of the judgement about the specified objective of the corresponding "bush" of the analytic structure, and the consistency of the judgement about sub-objectives of the objective of the "bush" of the objective structure being synthesized; B2) at the mathematical stratum, we will estimate the resources for attaining the objective and the degree of its attaining for their insufficient number.

Note that the results of psychological studies indicate the iterative nature of the analysis and synthesis of objectives; therefore, their stratification, recurring of logical procedures in direct (the SOA phase) and inverse (the SOS phase) directions during their realization and correlation of the results obtained promotes their coordination. Implementation of the indicated procedures and representation of their results based on formalized tools will allow us to objectify subjective models and methods of the analysis and synthesis of objectives and will make it possible to construct consistent analytic structures of perfect objectives, to substantiate the corresponding synthetic structures of real objectives and plans of attaining objectives, with a simplified formation and more efficient realization.

Psychological studies differentiate between two types of purposes: idealistic goals and realistic objectives. This gives an occasion to form initial (in) and final (fin) schemes of selection during the synthesis of objective-attaining schemes. Figure 2b shows the initial objective-attaining scheme formed from an analytic objective structure. According to the graph G^{a}, we generate the initial objective-attaining scheme and denote it by ${}^{\mathrm{in}}G^{\mathrm{c}}$: ${}^{\mathrm{in}}G^{\mathrm{c}} = (\mathrm{O}, R^{-1})$, where R^{-1} is the inversion of the relation *R*, i.e., the set of the arcs oriented in the direction inverse to *R*, and supplement it with the initial vertex (I) and the arcs that link I with "leaf" objectives of the analytic structure (we denote them by dashed lines like dummy activities in network plans).

Thus, in all triviality of the formation of the initial objective-attaining scheme, its result is consistent due to the consistency of corresponding analytic structure of objectives.

The initial objective-attaining scheme can be improved by specifying objectives (for example, by reducing the concepts appearing in their definitions) and due to the information that the subject of control obtains during the stages of the structural-objective analysis and synthesis of OES that link the stages of formation of the analytic and synthetic structures of objectives. As a result of such an improvement, the objective content usually varies: ${}^{\mathrm{fin}}G^{\mathrm{c}} = ({}^{\mathrm{fin}}\mathrm{O}, R^{-1})$.

Let us specify the realization of this scheme, corresponding to $G^{\mathrm{a}}_{t_i}$, as ${}^{\mathrm{fin}}G^{\mathrm{c}}_{t_p} = ({}^{\mathrm{fin}}\mathrm{O}, R^{-1}, t_p)$.

Note that time scales t_p $(p=0,1,2,\dots)$ and t_i $(i=0,1,2,\dots)$, as well as intervals between the moments t_p, t_{p+1} and t_i, t_{i+1}, can be different, and the graph ${}^{\text{fin}}G^{\text{c}}_{t_p}$, as well as the graph $G^{\text{a}}_{t_i}$, is a target plan. To distinguish them, like in [16], we will call the target plan $G^{\text{a}}_{t_i}$ preliminary, and ${}^{\text{fin}}G^{\text{c}}_{t_p}$ executive. The plan ${}^{\text{fin}}G^{\text{c}}_{t_p}$ is a frame for the plan of attaining the objectives defined in it. The objective-attaining plan is formed by associating each objective $o \in {}^{\text{fin}}O$ appearing in ${}^{\text{fin}}G^{\text{c}}_{t_p}$ with the problem and objective-attaining actions and resources allocated.

Note that the inconsistency and incompleteness of objective structures for traditional methods of their analysis and synthesis are due to numerous factors, such as:

• subjectivity of processes and high generality of their key concepts: "objective," "objective structure," and "strategy of the analysis (synthesis) of objectives;"

• insufficiently developed logical models, which could objectify intuitive methods of reasoning about the objectives being analyzed and synthesized, using linguistic and logical tools of the natural language;

• badly developed semantics of objectives, relationships between them, and indices of the estimate of consistency and entirety of objective structures.

These factors make analysis and synthesis of objectives uncertain, depend heavily on the quality of their results, and bring inconsistency and incompleteness to not only objective structures but to the subsequent results of the systems analysis of OES.

7. WAYS OF SOLVING LOGICAL PROBLEMS IN SYSTEMS ANALYSIS OF OES

The author proposes the following ways to solve two basic logical problems in the systems analysis of OES.

1. Providing consistency of the results of the analysis and attaining objectives by formalizing the reasoning on OES objectives.

2. Providing consistency of the results of isolated stages of the systems analysis of OES by specifying and formalizing the logical aspect of its regulative basis.

In view of the above formalizations, it will become possible to model a reasoning about the objectives being analyzed and taken as a control subject, to formalize the analysis of possible errors of subjective attaining of an objective and to form guidelines for their timely correction, as well as the synthesis of logically correct schemes and systems, programs and plans of attaining objectives. Taking into account the variety of types and classes of objectives, the complexity and uncertainty of their statements, discursive reasoning on these objects can be modeled only in view of the semantics of objectives, relationships between them, and logical characteristics of their structures. To make the analysis and objective-attaining processes consistent, the following is necessary: (i) to reveal the laws governing the realization of the processes in OES; (ii) to formalize the semantics of objectives, the relationships between them, and the properties of objective structures; (iii) to use it as a basis to design a theory of reasoning about the objectives being analyzed and attained; and (iv) to implement this theory in a model of reasoning about objectives. Preventing logical inaccuracies, this model will provide consistency of objective (results of analysis and attaining objectives), and hence consistency of all subsequent results of structural-objective analysis and synthesis of OES.

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